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MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command
DETAIL CALCULATIONS OF THE ESTIMATED SHIFT IN
STICK-FIXED NEUTRAL POINT DUE TO THE
WINDMILLING PROPELLER AND TO THE
FUSELAGE OF THE REPUBLIC XF-12 AIRPLANE

By M. D. White

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Langley Field, Va.

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DETAIL CALCULATIONS OF THE ESTIMATED SHIFT IN
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SUMMARY

Detail calculations are presented of the shifts in stick-fixed neutral point of the Republic XF-12 airplane due to the windmilling propellers and to the fuselage. The results of these calculations differ somewhat from those previously made for this airplane by Republic Aviation Corporation personnel under the direction of Langley flight division personnel. Due to these differences the neutral point for the airplane is predicted to be 37.8 percent mean aerodynamic chord instead of 40.8 percent mean aerodynamic chord as previously reported.

INTRODUCTION

At the request of the Army Air Forces, Air Technical Service Command, the following report has been prepared describing in detail the methods used in estimating the shift in stick-fixed neutral point due to the windmilling propeller and to the fuselage. Because the original calculations, which were made by Republic Aviation Corporation personnel under the direction of Langley flight division personnel, were in the possession of the Republic company it was necessary in preparing the report to repeat the calculations. These check calculations indicate several discrepancies in the original calculations which are noted in this report.

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CALCULATION PROCEDURE

General procedure.- The procedure used in calculating the neutral point of an airplane is to calculate the shift in neutral point due to each component and then to determine the center-of-gravity position at which the resultant of all the shifts in neutral point is equal to zero. Application of this procedure to the XF-12 airplane is illustrated in figure 2 where the shift in neutral point due to each of the components considered is plotted against center-of-gravity position.

In a procedure equivalent to determining the center-of-gravity position at which the resultant of the neutral point shifts is zero, the negative of the resultant of all the values of forward neutral-point shift is plotted against center-of-gravity position (curve 1, fig. 2), and the neutral point is established as the center-of-gravity position at which this curve intersects the resultant of all the values of rearward neutral-point shift, which in this case is the shift due to the horizontal tail (curve 5).

It will be noted that the present calculations indicate the neutral point to be at 37.8 percent mean aerodynamic chord instead of 40.8 percent mean aerodynamic chord as noted in reference 1. The sources of the erroneous values given in reference 1 are indicated in the following sections describing the detailed calculations of the shifts in neutral point due to the propeller and the fuselage and nacelles.

Propeller moments.- The neutral point shift due to the normal force on the windmilling propellers is given by the expression

$$\Delta n_p = \frac{\left[1 + \left(\frac{d\epsilon}{da} \right)_{\text{prop}} \right] l_p \frac{\pi}{4} D^2 \left(\frac{dC_N}{d\psi} \right)_{\text{prop}}}{S c \frac{dC_L}{da}}$$

where

$\left(\frac{d\epsilon}{da} \right)_{\text{prop}}$ rate of change of upwash with angle of attack at the propeller plane

l_p horizontal distance from the center of gravity to the propeller plane, feet

D propeller diameter, feet

$\left(\frac{dC_N}{d\psi}\right)_{\text{prop}}$ rate of change of propeller normal force with angle of attack of thrust axis, per radian ($C_{Y\psi}$ in reference 2)

The application of this expression to the XF-12 airplane is illustrated in table I, using a value of l_p corresponding to a center-of-gravity location of 40.8 percent mean aerodynamic chord, and in figure 2 the variation of this neutral-point shift with center-of-gravity position is indicated (curve 4).

The additional shift in neutral point due to the downwash from the windmilling propellers is assumed to be given by the approximate expression

$$\Delta n_{\epsilon_p} = -\Delta n_{\text{hor. tail}} \frac{\left(\frac{dC_N}{d\psi}\right)_{\text{prop}} \left[1 + \left(\frac{d\epsilon}{d\alpha}\right)_{\text{prop}}\right]}{4 \left[1 - \left(\frac{d\epsilon}{d\alpha}\right)_{\text{tail}}\right]}$$

This expression is derived by calculating the downwash in the slipstream from momentum considerations, and reducing the value by an empirical coefficient to take into account the effects of the wing, fuselage, and other factors on the propeller downwash.

Inserting the values corresponding to a center-of-gravity position of 40.8 percent mean aerodynamic chord

$$\Delta n_{\epsilon_p} = -0.428 \frac{(0.43)(1.35)}{4(0.66)} = -0.094$$

This value differs by 0.032 from the shift of 0.062 quoted in reference 1. It is difficult at this time to determine the source of the discrepancy due to the fact that the original calculations are in the possession of the Republic company. It appears, however, from the magnitude of the discrepancy that the factor

$\left[1 - \left(\frac{d\epsilon}{d\alpha} \right)_{\text{tail}} \right]$ was omitted in the original calculations.

The corrected variation of the neutral point shift due to propeller downwash with center-of-gravity position is indicated as curve 2, figure 2.

Fuselage and nacelle moments. - The shift in stick-fixed neutral point due to a fuselage or nacelle is given by the expression

$$\Delta n_b = \frac{\frac{1}{q} \left(\frac{dM}{d\alpha} \right)_b}{S \cdot c \cdot \frac{dC_L}{d\alpha}}$$

where

q dynamic pressure, pounds per square foot

S wing area, square feet

c mean aerodynamic chord, feet

$\frac{dC_L}{d\alpha}$ wing lift-curve slope, per radian

$\left(\frac{dM}{d\alpha} \right)_b$ rate of change of pitching moment of fuselage or nacelle, per radian

From reference 2 $\frac{1}{q} \left(\frac{dM}{d\alpha} \right)_b$ is given by the expression

$$\frac{1}{q} \left(\frac{dM}{d\alpha} \right)_b = \frac{\pi}{2} \int b^2 \left(\frac{d\beta}{d\alpha} \right) dx$$

where

b fuselage or nacelle width, feet

$\frac{d\beta}{d\alpha}$ rate of change of air flow inclination from airplane axis with angle of attack

x distance along X-axis of fuselage or nacelle, feet

The integral is taken along the entire length of the fuselage or nacelle. Ahead of the wing, values of $\frac{d\beta}{d\alpha}$ are given by the curves of figure 8, reference 1. Behind the wing, the value of $\frac{d\beta}{d\alpha}$ is assumed to vary linearly with distance from a value of zero at the wing trailing edge to a value of $1 - \frac{d\epsilon}{d\alpha}$ at the mean $\frac{1}{4}$ -chord point of the horizontal tail. Between the wing leading edge and trailing edge the value of $\frac{d\beta}{d\alpha}$ is assumed to be zero.

The evaluation of the integral, $\int b^2 \left(\frac{d\beta}{d\alpha} \right) dx$, is accomplished by dividing the fuselage and nacelles into sections, as indicated in figure 1, and calculating the value, $b^2 \left(\frac{d\beta}{d\alpha} \right) \Delta x$, for each section, using an average integrated value of $\frac{d\beta}{d\alpha}$ for the section directly ahead of the wing (section I in figure 1) and using average values of $\frac{d\beta}{d\alpha}$ for the other sections. The resultant value of $\int b^2 \left(\frac{d\beta}{d\alpha} \right) dx$ is then obtained by summing up the values for all the sections. Using this procedure detailed calculations for the XF-12 airplane are indicated in tables II and III.

Table IV gives detailed calculations of the effect of the nacelles on the wing which, according to page 12 of reference 2, is given by the expression

$$\frac{1}{q} \left(\frac{dM}{d\alpha} \right) = \frac{\pi}{16} \left(b_{L.E.} + 2b_{middle} - 3b_{T.E.} \right) c^2$$

where

$b_{L.E.}$ nacelle width at wing leading edge

b_{middle} nacelle width at mid-chord station

$b_{T.E.}$ nacelle width at wing trailing edge

c wing chord at nacelle position

Combining all the values of $\frac{1}{q} \left(\frac{dM}{da} \right)$ as shown at the end of table IV, a shift in neutral point of 0.093 is indicated, which differs slightly from the value of 0.087 plotted in figure 2 of reference 1; it appears from the magnitude of this difference that the effect of the nacelles on the wing, calculated in table IV, was neglected.

CONCLUSIONS

Check calculations of the shift in stick-fixed neutral point due to the fuselage and to the windmilling propellers of the Republic XF-12 airplane have indicated several errors in the original calculations. The check calculations indicate the predicted stick-fixed neutral point to be at 37.8 percent mean aerodynamic chord instead of 40.8 mean aerodynamic chord as previously reported.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., October 16, 1944

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1. Langley Flight Research Division: Estimation of the Stability and Control Characteristics of a Republic XF-12 Airplane, NACA Memo. for Army Air Forces, June 8, 1944.
2. Multhopp, H.: Aerodynamics of the Fuselage. NACA TM No. 1036, 1942.
3. Ribner, Herbert S.: Formulas for Propellers in Yaw and Charts of the Side-Force Derivative. NACA ARR No. 3E19, 1943.

TABLE I.- DETAILED CALCULATIONS OF THE SHIFT IN
STICK-FIXED NEUTRAL POINT DUE TO THE NORMAL
FORCE ON THE WINDMILLING PROPELLERS

	Inboard propeller	Outboard propeller
1. c_3 , ft (fig. 1)	15.35	12.8
2. l_1 , ft (fig. 1)	9.6	10.0
3. l_1/c_3	.625	.781
4. $1 + \left(\frac{dc}{da}\right)_{\text{prop}}$ (fig. 8, reference 2)	1.35	1.30
5. l_p , ft (fig. 1)	15.95	15.05
6. D , propeller diameter, ft	16.16	16.16
7. D^2	261	261
8. $(dc_N/d\psi)_{\text{prop}}$ (fig. 13, reference 3)	.43	.43
9. $\frac{\pi}{4} \times (4) \times (5) \times (7) \times (8)$	1900	1722

$$\Delta n_p = \frac{-2 \left[1 + \left(\frac{dc}{da}\right)_{\text{prop}} \right] \times l_p \times \frac{\pi}{4} \times D^2 \times \left(\frac{dc_N}{d\psi}\right)_{\text{prop}}}{S \times c \times \frac{dc_L}{da}}$$

$$= - \frac{2(1900 + 1722)}{1640 \times 13.43 \times 4.81}$$

$$= - 0.068$$

TABLE II.- DETAILED CALCULATIONS OF THE SHIFT IN

STICK-FIXED NEUTRAL POINT DUE TO THE FUSELAGE

(a) Fuselage Forward of Wing

Section	c_1 , ft (fig. 1) (1)	x_0, x_1 , ft (fig. 1) (2)	$\frac{x_0}{c_1}, \frac{x_1}{c_1}$ (3)	$\left(\frac{d\beta}{da}\right)_a = 4.5$ (fig. 8, reference 2) (4)	$\left(\frac{d\beta}{da}\right)_a = 4.81$ (5)	b , ft (fig. 1) (6)	b^2 (7)	Δx , ft (fig. 1) (8)	$(5) \times (7) \times (8)$ (9)
I	17.0	10.0	0.588	2.16	2.31	9.73	94.67	10.0	2186.9
II	17.0	13.33	.785	1.21	1.29	8.64	74.65	6.67	642.3
III	17.0	18.33	1.080	1.15	1.23	7.20	51.84	3.33	212.3
IV	17.0	21.67	1.275	1.12	1.20	5.76	33.18	3.33	132.6
V	17.0	25.25	1.488	1.10	1.18	3.37	11.36	3.83	51.3
									3225.4

$$\frac{\pi}{2} \times 3225.4 = 5067.2$$

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TABLE II.- DETAILED CALCULATIONS OF THE SHIFT IN

STICK- FIXED NEUTRAL POINT - Concluded

(b) Fuselage Aft of Wing

Section	c_2 , ft (fig. 1) (1)	x_2 , ft (fig. 1) (2)	$\frac{x_2}{c_2}$ (3)	$1 - \frac{d\epsilon}{d\alpha}$ (4) (a)	b , ft (fig. 1) (5)	b^2 (6)	Δx , ft (fig. 1) (7)	(4) \times (6) \times (7) (8)
VI	40.9	5.0	0.122	0.064	9.9	97.22	10	62.2
VII	40.9	15.0	.367	.191	9.0	81.00	10	155.0
VIII	40.9	23.3	.570	.297	7.8	60.84	6.7	121.2
IX	40.9	30.0	.733	.382	6.5	42.25	6.7	108.3
X	40.9	36.7	.897	.467	4.5	20.25	6.7	63.4
XI	40.9	41.7	1.020	.530	2.7	7.29	3.3	12.8
XII	40.9	45.9	1.122	.635	1.2	1.44	5.0	4.6

527.5

^aThis value is corrected for the effect of propeller downwash by multiplying the value of $1 - \frac{d\epsilon}{d\alpha}$ for the plain wing (0.66) by the ratio of

$$\frac{\pi}{2} \times 527.5 = 829$$

$$\frac{\Delta n_t - \Delta n_{\epsilon_p}}{\Delta n_t} = \frac{0.428 - 0.095}{0.428}$$

$$= \frac{0.333}{0.428}$$

$$= 0.78$$

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TABLE III.- DETAILED CALCULATIONS OF THE SHIFT IN
STICK-FIXED NEUTRAL POINT DUE TO THE NACELLES

Section	Inboard nacelle		Outboard nacelle	
	XIII	XIV	XV	XVI
1. c_3 , ft (fig. 1)	15.35	15.35	12.8	12.8
2. x_0 , x_1 , ft (fig. 1)	8.14	9.44	8.44	9.74
3. x_0/c_3 , x_1/c_3	.53	.615	.66	.76
4. $(d\beta/da)_a = 4.5$ (fig. 8, reference 2)	2.28	1.27	2.06	1.22
5. $(d\beta/da)_a = 4.81$	2.44	1.36	2.20	1.30
6. b , ft (fig. 1)	5.1	1.9	5.1	1.9
7. b^2	26.01	3.61	26.01	3.61
8. Δx , ft (fig. 1)	8.14	2.74	8.44	2.74
9. $(5) \times (7) \times (8)$	516.6	13.5	483.0	12.9

$$516.6 + 13.5 + 483.0 + 12.9 = 1026.0$$

$$2 \times \frac{\pi}{2} \times 1026 = 3220$$

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TABLE IV.- DETAILED CALCULATIONS OF THE SHIFT IN STICK-FIXED
NEUTRAL POINT DUE TO THE EFFECT OF THE NACELLES ON THE WING

	Inboard nacelle	Outboard nacelle
1. $b_{L.E.}$, ft	5.33	5.23
2. b_{middle} , ft	4.76	4.70
3. $2b_{middle}$	9.52	9.40
4. $b_{T.E.}$, ft	3.26	3.50
5. $3b_{T.E.}$	9.78	10.50
6. (1) + (3) - (5)	5.07	4.13
7. c_3 , ft	15.35	12.5
8. c_3^2	235.7	156.2
9. (6) \times (8)	1193	646

$$1193 + 646 = 1839$$

$$2 \times \frac{\pi}{16} \times 1839 = 721$$

$$\frac{1}{q} \frac{dM}{da_{total}} = 5067 + 829 + 3220 + 721 = 9837$$

$$\Delta n_b = \frac{9837}{1640 \times 13.43 \times 4.81} = 0.093$$

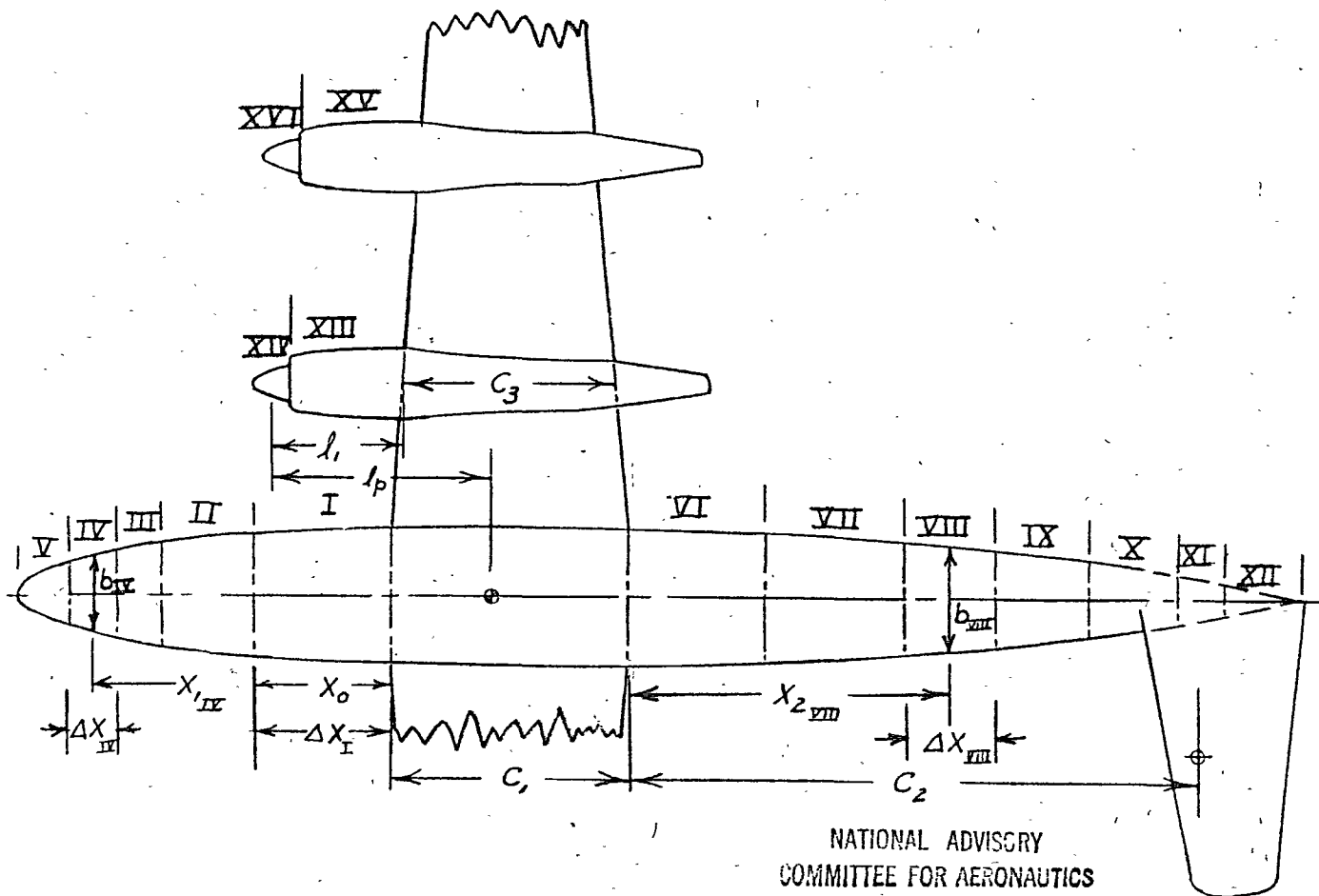


Figure 1. - Definition of symbols used in memorandum.

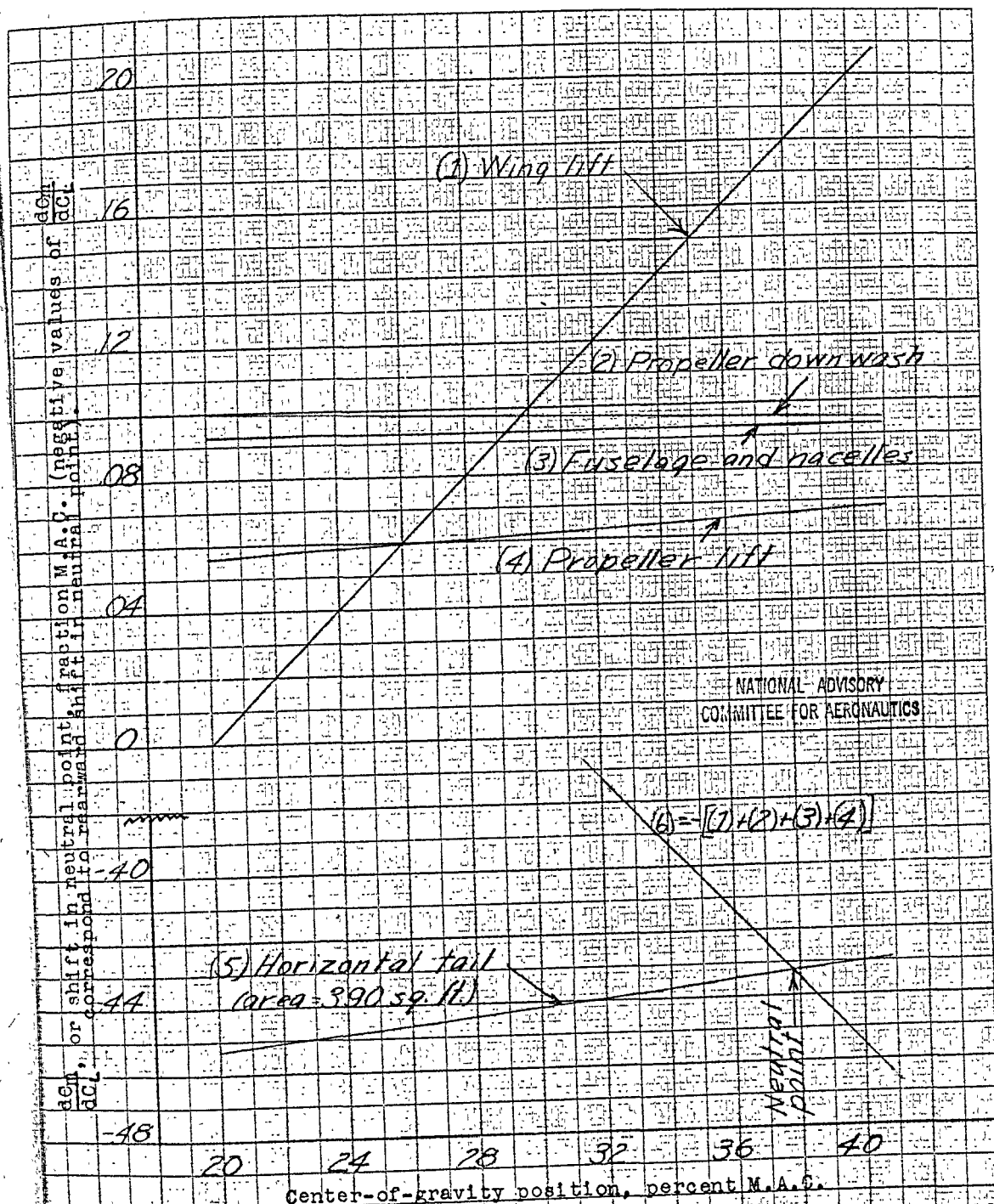


Figure 2. - Corrected variation of neutral-point shift with center-of-gravity position for components considered in neutral-point calculations. Flaps neutral, propellers windmilling, Republic XF-12 airplane.